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A conceptual framework for environmental flows assessment based on ecosystem services and their economic valuation

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ABSTRACT

In recent decades, environmental flows has emerged a major instrument for sustaining and/or rehabilitating the ecosystem functions and services of rivers worldwide. The holistic methodologies of assessment of environmental flows (=EFlows) take into account the physical, biological, water quality and socio-cultural as well as livelihood aspects of riverine ecosystems, and increasingly depend upon consultations with experts and local communities to make a negotiated socio-political decision by consensus within the society. This paper presents a conceptual framework for the assessment of EFlows on the basis of a change in total ecosystem services and their total economic value with the alteration of flow regimes. Such an assessment would consider the gain and loss of ecosystem services both upstream and downstream of the point of intervention which alters the flow regime. It is also proposed that the economic valuation should provide for appropriate weightages to ecosystem services with a strong social, cultural and livelihood bearing in regional/local context. It is further argued that a top-down approach to E-Flows assessment should be followed wherever possible to convince the policy makers.

1. Introduction

Humans have interfered with river flows for millennia by diverting water for irrigating their croplands. Long-term consequences of irrigation in the Indus valley are well known to have caused salinisation of soils and loss of fertility (Goudie, 2009). Shorter-term impacts on fish and wildlife resources were recognised in early decades of the 20th century after dams and barrages were constructed for diversion and storage of river flows. However, numerous hydropower projects in northwest USA during 1970s triggered the debate and studies on the 'in-stream flow needs' or 'in-stream flow requirements' of fish populations, mostly salmon and freshwater trout, from the perspective of regulatory agencies and fisheries management. The landmark symposium of the American Fisheries Society in 1976 (Orsborn and Allman, 1976) gave birth to the concept of 'minimum flow' which was strongly criticised soon thereafter (Stalnaker and Arnette, 1976; Stalnaker 1990).

Over the next three decades, human interest in natural river flows moved gradually beyond the 'in-stream' needs of fisheries. Our improved understanding of the river ecosystems brought into focus the issues of habitat diversity, various components of biodiversity other than fish, water quality and ecosystem functions (Gopal and Chauhan, 2013). These issues were addressed by the researchers in North America by elaborating the scope and definition of in-stream flows as "*the amount of water flowing through a natural stream course that is* ***needed*** *to sustain, rehabilitate, or restore the ecological functions of a stream in terms of hydrology, geomorphology, biology, water quality, and connectivity at a particular level*" (Annear et al., 2004). However, the issues of river flows were soon linked with the overall water resources management and the discussions started considering the flow requirements for the livelihood and socio-cultural needs of downstream communities. The IUCN promoted the term 'environmental flows' (Dyson et al., 2003) which was later adopted by the Brisbane Declaration (2007) stating that, "*Environmental flow describes the quantity, quality and timing of water flows* ***required*** *to sustain freshwater ecosystems and the human livelihoods and well-being that depend on these ecosystems*".

As these definitions show, greatest attention has been paid to the 'need' or 'requirement' of the river to sustain or rehabilitate its functions because the issues arose from the concerns caused by degradation. The regulatory agencies did never consider placing a cap on the amount of water that could be stored and diverted without affecting the fisheries and other downstream uses. Silk et al. (2000) did examine the possibility of 'directly specifying a level of water development and protecting the remaining flows in the stream' and argued for legal recognition of 'upside-down in-stream flow water rights' especially to protect complex flow patterns.

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1.1. Environmental flows assessments

Environmental flows and their assessment have been discussed in many countries and different types of rivers but detailed investigations have been confined to a few countries. Numerous methodologies have been developed over the past four decades and reviewed time to time in a variety of publications (Jowett, 1997; Tharme 2003; Arthington 2012; Linnansaari et al., 2012; Gopal 2013). However, these methodologies in general represent steps in their evolution that started with simple approaches based upon only hydrological and hydraulic parameters. The EFlows assessment methodology gradually grew in complexity with the inclusion of habitat requirements of specific biota and some environmental aspects such as sediment transport, water quality and fish passage (Habitat Simulation methods) and later, by considering the whole riverine ecosystem (Holistic methodologies). Still later were introduced the socio-economic and livelihood considerations into the assessment methodologies such as DRIFT and ELOHA (Brown et al., 2008, 2013; Poff et al., 2010). Conceptually, the EFlows requirement is assessed for all abiotic and biotic components of the river ecosystem on a basin-wide scale, including the associated wetlands, groundwater and estuaries (see Arthington, 2012). However, neither flow-ecology relationships involving multiple variables nor the monitoring and evaluation of implemented E-flows have received much attention (Davies et al., 2014).

2. Linking EFlows with ecosystem services

There is a growing recognition of the need for a wider perspective of the EFlows issue taking into account the functions of a river ecosystem in totality as well as considering the social, cultural and livelihood interests of local river-dependent communities. It is indeed extremely difficult to investigate the impacts of flow regulation on all ecosystem components, processes and functions of a river within a short time. In this context, the ecosystem services concept which is rapidly gaining wide acceptance can be quite useful. The Millennium Ecosystem Assessment (MEA) defined ecosystem services simply as “the direct and indirect benefits derived by humans” (MEA, 2005). The MEA grouped various ecosystem services into four broad categories- the Provisioning, Regulating, Cultural and Supporting services – but also recognised that some of them such as water can be placed in two or more categories. The MEA framework was not intended to be perfect and instead, has stimulated much discussion on the definition and classification of the ecosystem services that has gone into making a distinction between goods and services, services and benefits, and intermediate and final services, and development of several classification schemes (Costanza, 2008; Fisher et al., 2009, de Groot et al., 2010a,b, Haines-Young and Potschin, 2013; Landers and Nahlik 2013). However, a single internationally accepted classification may not be practically possible because of the need to consider the characteristics of the ecosystems and their services and the decision-making context (Fisher et al., 2009). In the meantime, the MEA categorization with small changes in identifying various ecosystem services continues to be followed most widely and is used in this article.

Ecosystem services (including the goods, sensu Costanza, 2008) are derived from the interaction between different biotic and abiotic components and functions of the ecosystem. Therefore any natural or human intervention that has an impact on any of the components or function will cause some change in the ecosystem services. Mueller and Burkhard (2012) consider ecosystem services as ecological indicators which may be seen as a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals (cf. Heink and Kowarik, 2010). Hence I propose that the relationships between the flow regimes and ecosystem services, as elaborated in the following sections, should be employed in the assessment of environmental flows by determining the thresholds of water abstraction or the releases for obtaining desired levels of ecosystem services. Because the assessment of some ecosystem services remains qualitative, economic valuation should also be combined with the assessment of various ecosystem services. It will offer an opportunity to bring them into consideration of the policy- and decision makers relatively easily.

Table 1
Major ecosystem services of rivers governed by their flows.

Category	Ecosystem services
Provisioning	Making water available (including groundwater) for different uses (domestic, irrigation, hydropower) Water for transport of materials and people Plant material (for food, fibre, fuel, biochemicals) Animals (fish, prawn, grazers) for food and other uses Sediments (including gravel) for construction
Regulating	Moderation of microclimate along the river Water quality improvement (waste assimilation) Renewal of soil fertility Erosion control and flood regulation (riparian/floodplain vegetation) Storm protection (through mangroves) in tropics Regional climate (through influence on sea salinity) Regulation of pests and diseases
Supporting	Soil formation (as in floodplains) Habitats for biodiversity (all groups)
Cultural	Water based recreation and sport Cultural/religious activities Specific spiritual / inspirational links Heritage sites Opportunity for livelihoods Enhanced aesthetics of the riverscape

2.1. Ecosystem services of rivers

Rivers provide a variety of ecosystem services (Table 1) which started receiving some attention only recently and largely in the context of restoration of degraded rivers (e.g. Loomis et al., 2000; Holmes et al., 2004; Kaval, 2011; Russi et al., 2013; Vermaat et al., 2014; Auerbach et al., 2014). Ecosystem services such as fisheries, habitat support for biota, water quality improvement, groundwater recharge by floodplain wetlands, and recreation have been particularly emphasised (Dufour et al., 2010, Rouquette et al., 2011). All ecosystem services of a river are controlled by its flow regime that determines the channel characteristics, biodiversity and various ecosystem processes. For example, a change in fish catch (species composition and/or total yield) clearly indicates a change in the system without specifying the nature of all those changes which may depend on flow regime. In River Ganga, increased dominance of exotic common carps (*Cyprinus carpio*) is directly attributed to the reduction in its flows (Vass et al., 2010). A decline in flow reduces the interaction between the channel and the floodplain affecting the floodplain processes which regulate water quality and biodiversity. Flows also influence directly the recreational and cultural use of the rivers.

In linking ecosystem services with flow regimes, it is important to recognize that the flow alterations may occur at any or all stages of low, medium or peak flows or in the frequency and velocity of discharge. Further, the relationships of various ecosystem components with the flow regime are non-linear and widely different,